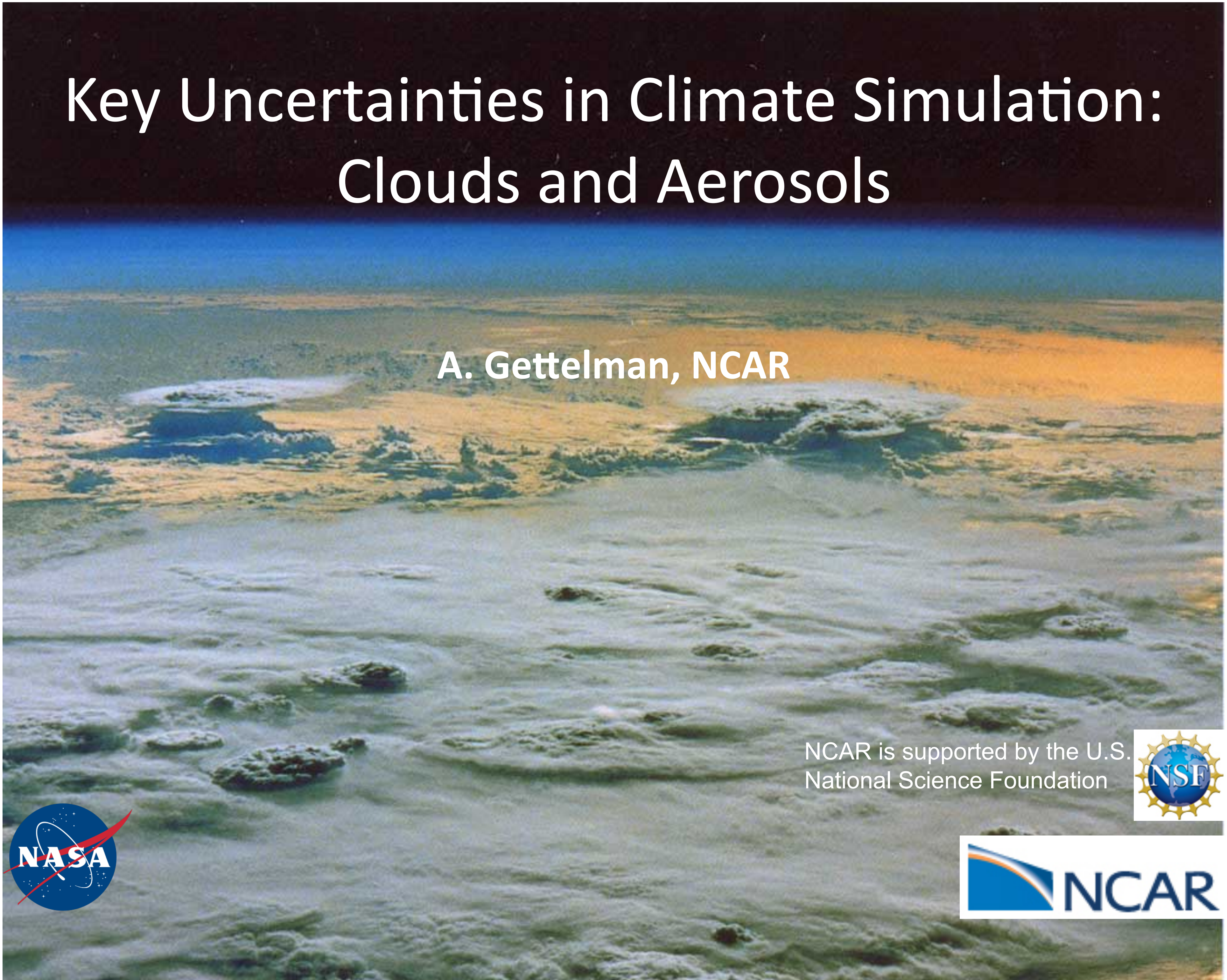
Key Uncertainties in Climate Simulation: Clouds and Aerosols

A. Gettelman, NCAR



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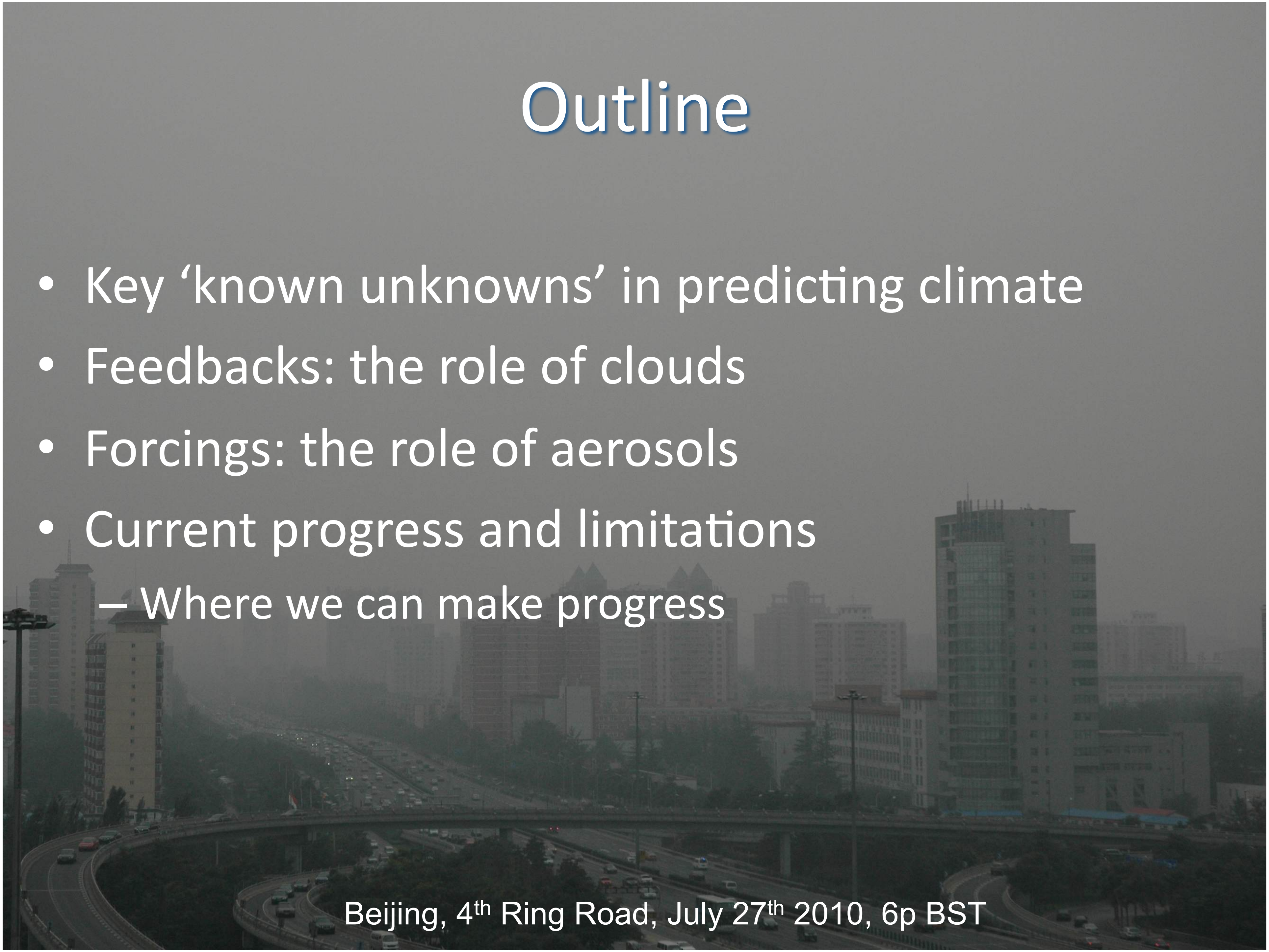
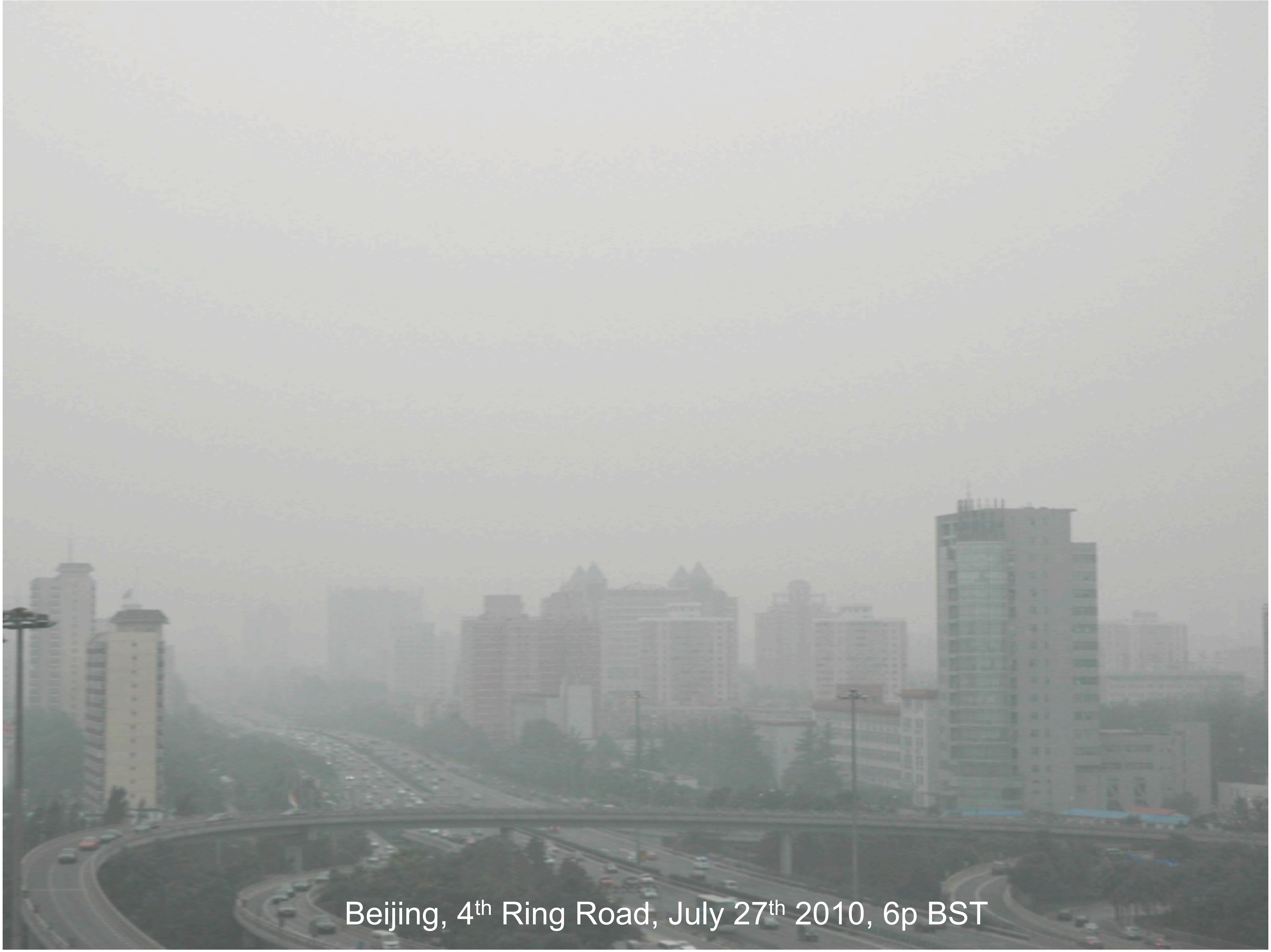
Outline

- Key 'known unknowns' in predicting climate
- Feedbacks: the role of clouds
- Forcings: the role of aerosols
- Current progress and limitations
  - Where we can make progress



Beijing, 4th Ring Road, July 27th 2010, 6p BST



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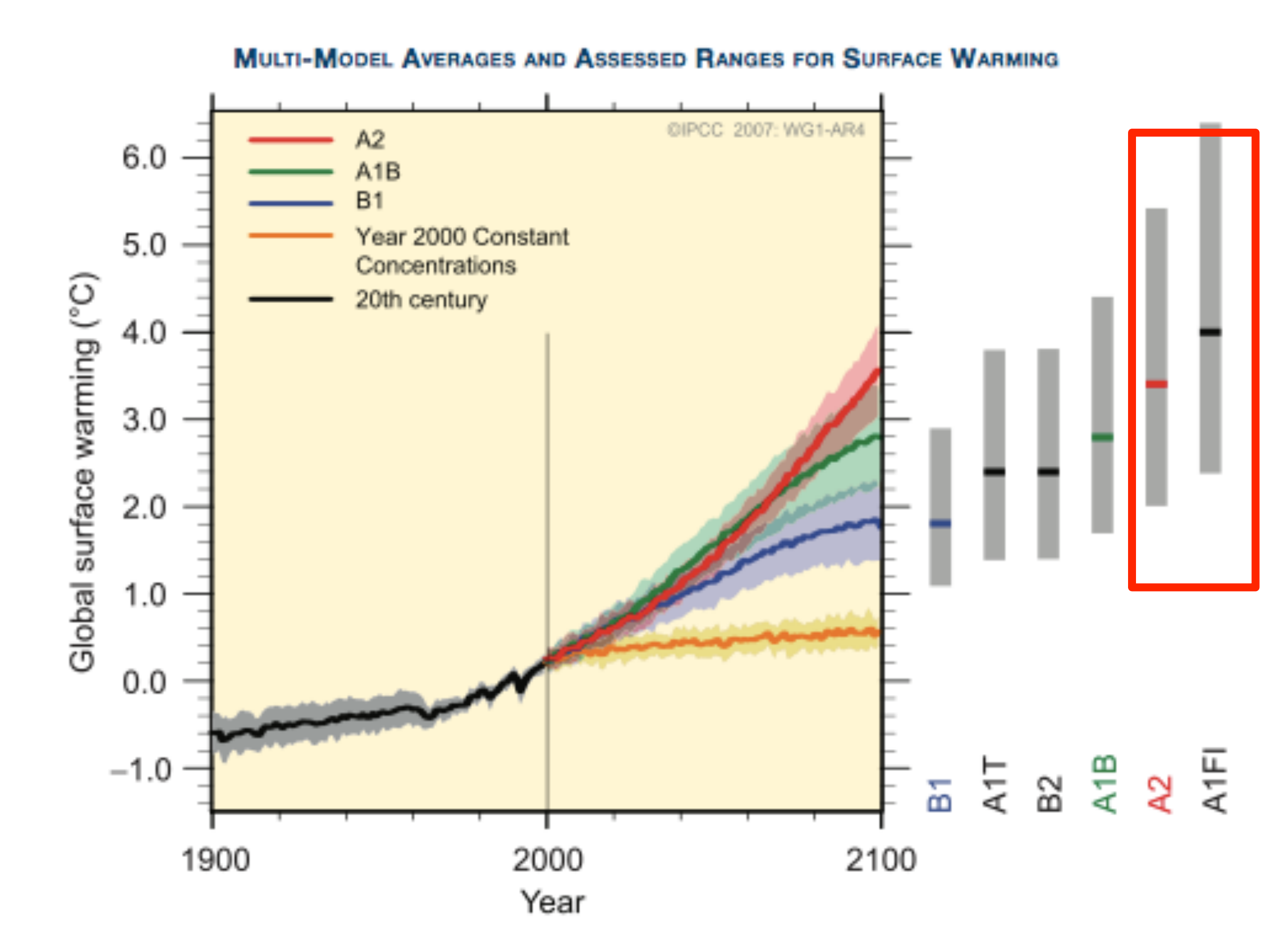
What will future climate be?

Use models to simulate: our best guess is uncertain



Notes:

Our current trajectory looks like A2 or A1FI !

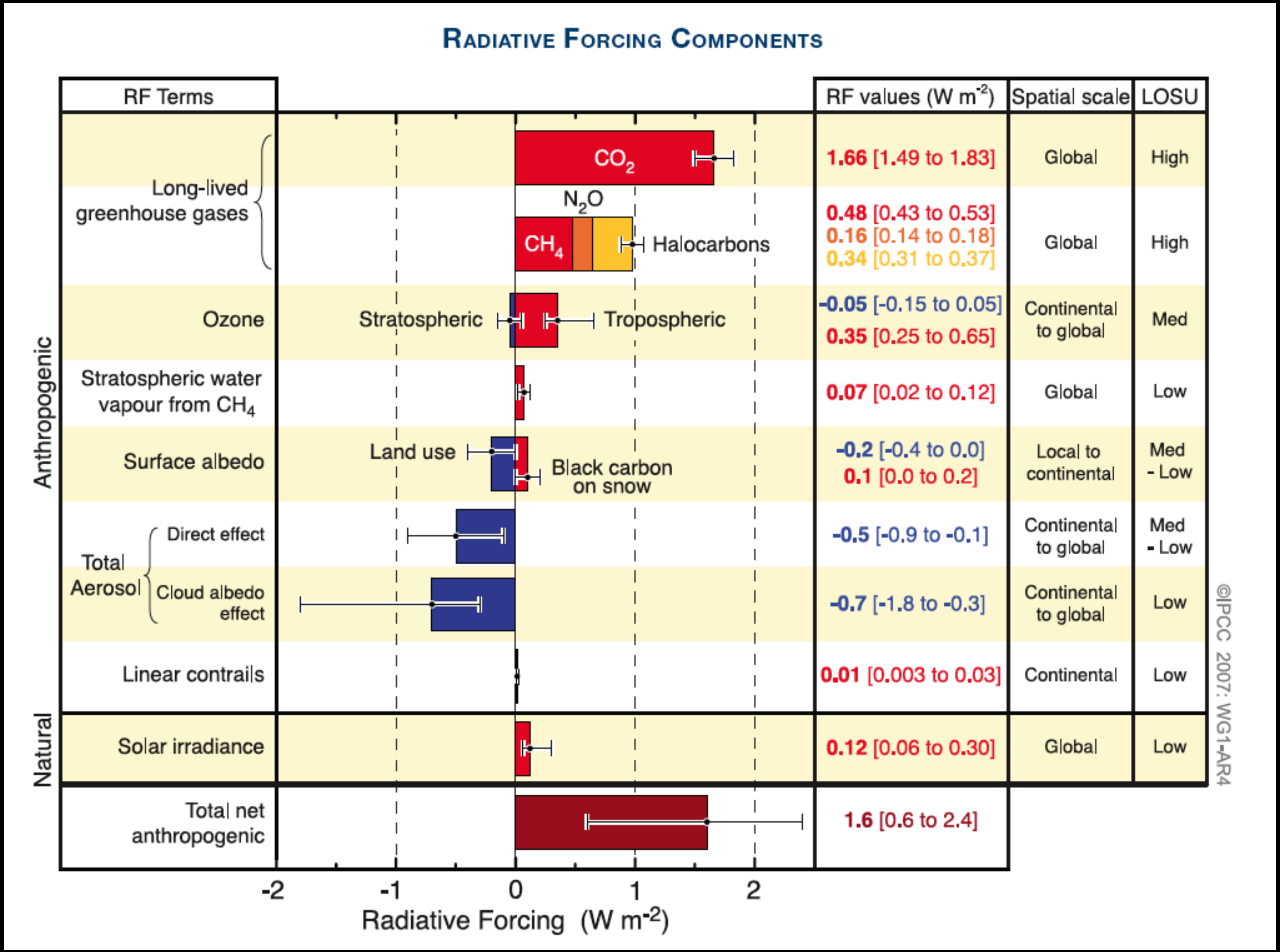
Spread within each scenario is large. Even when we understand the carbon cycle (carbon scenario), uncertainties are large. Why?

IPCC 2007 Policymakers Summary Figure 5

Predicting future climate

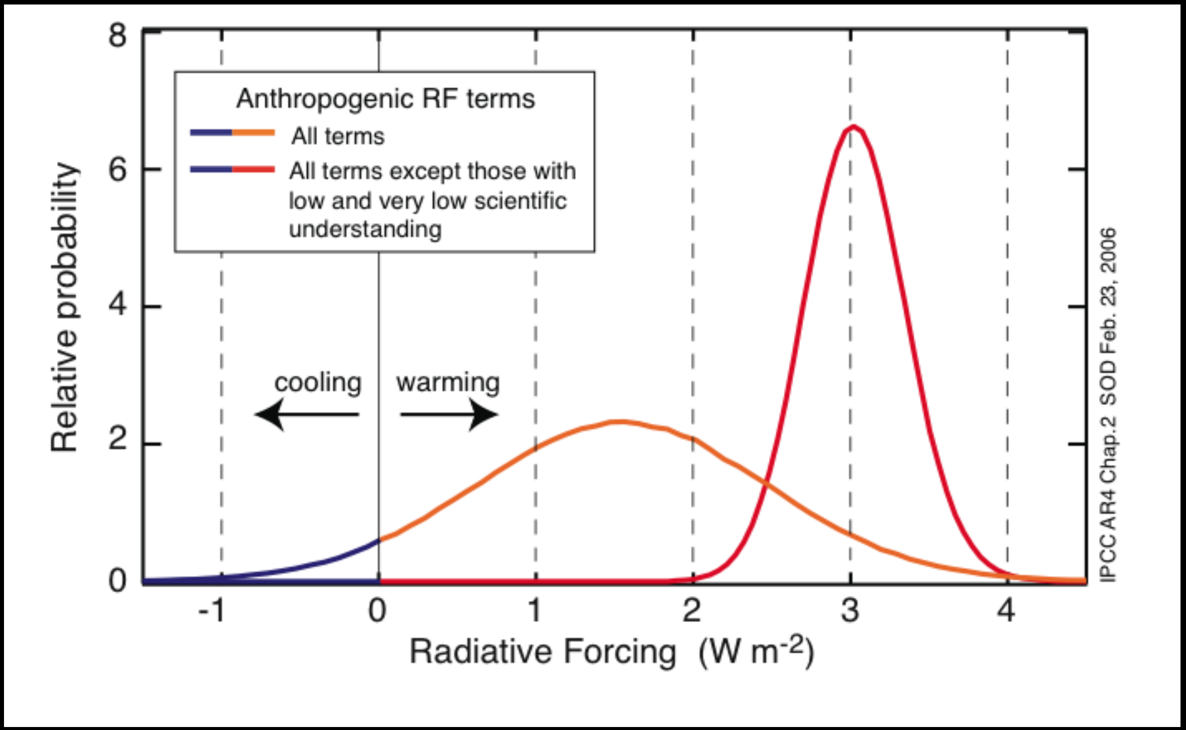
- Current state of the art models
  - Approaching global weather resolving models (50-25km)
  - Detailed satellite simulators for evaluation
    - Reduce retrieval uncertainty
  - Include ocean, land, sea ice
- Where we are going:
  - Global cloud permitting (5-15km) or cloud resolving (1km or less) models for climate (>10yrs)
  - Hybrid: high-resolution parameterizations of cloud dynamics, embedded in General Circulation models
  - Will want observations at these scales
  - Include ice sheet and carbon cycle models

Radiative Forcing



IPCC 2007 Policymakers Summary Figure 2

Radiative Forcing Uncertainty



- Anthropogenic 'forcing' F = ~3Wm^{-2} – Aerosol Effect (AE)
- If AE large, then net forcing (F) is small for fixed DT (1^{o}C)
- Aerosol effects alter 'observed' climate sensitivity (g) (F=DT/g)

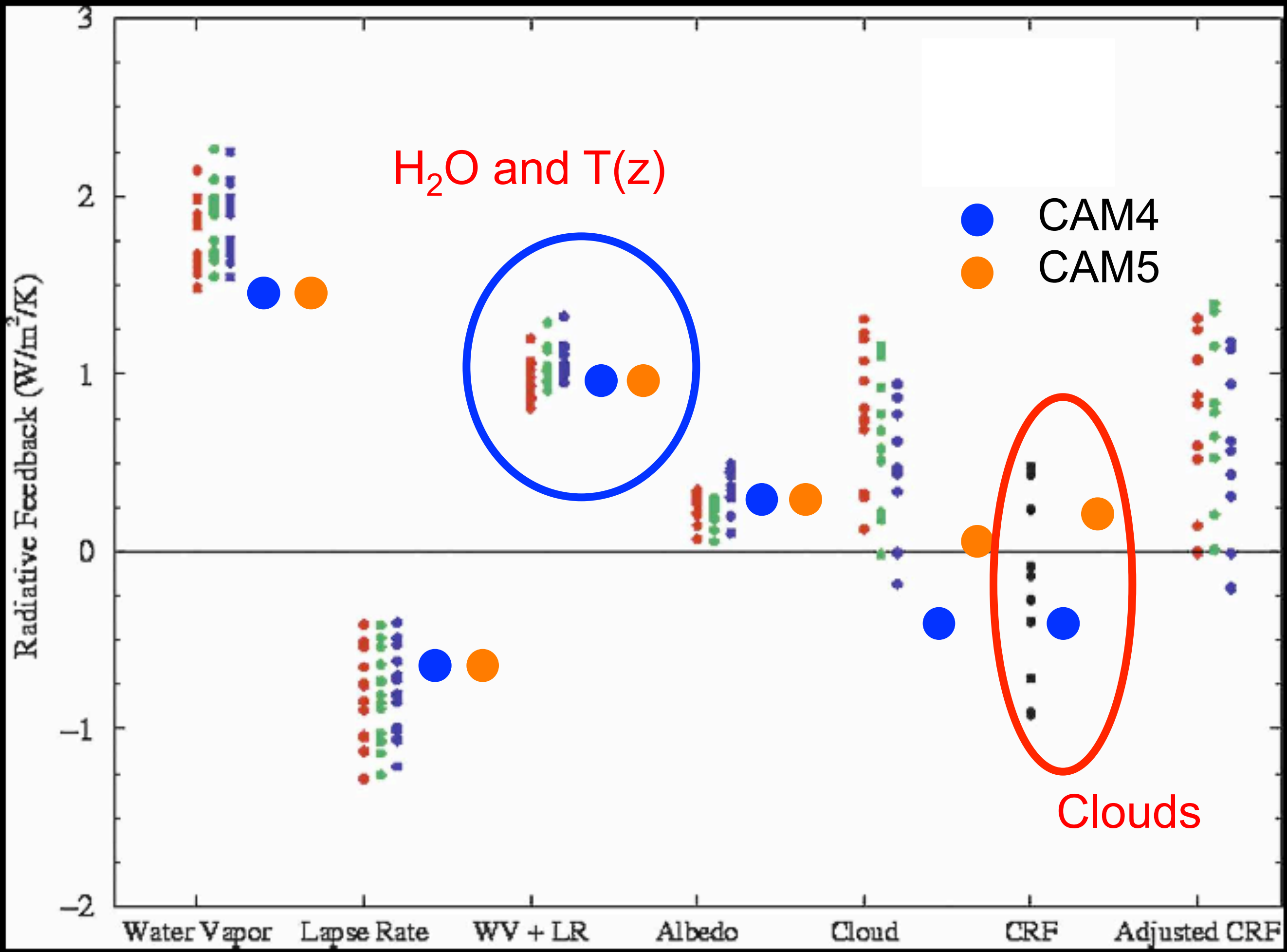
g = DT / F for fixed DT, AE reduces F, g is larger

'Feedbacks'

- $2xCO_2$ = +4W/m2 Forcing.
  - not the whole story!
- Half of expected warming is from 'feedbacks'
- Example: Water vapor feedback: +T $\rightarrow$ +H_2O, since H_2O is a greenhouse gas, +H_2O $\rightarrow$ +F
  - necessary to keep earth habitable
- Climate Feedbacks determine climate sensitivity (and DT if F is known)

Different Climate Feedbacks

- The Water Vapor feedback is large, positive and has small spread
- The sign of cloud feedback is uncertain
- Spread in cloud feedbacks as large as the Water Vapor feedback (1.5$Wm^{-2}K^{-1}$)

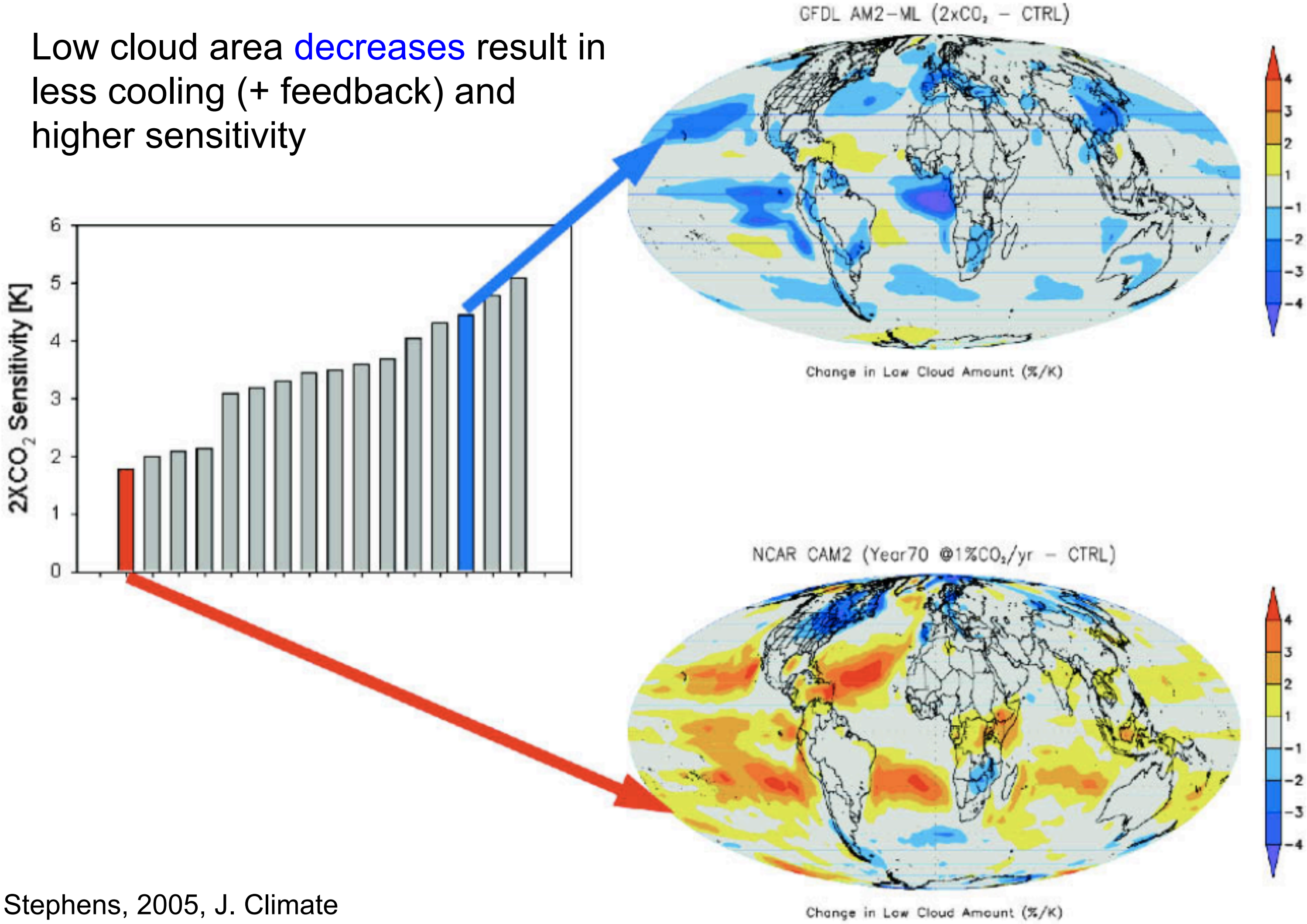


Soden, 2008 (also Colman, Bony)

Cloud Feedbacks affect Sensitivity

Models with - cloud feedback are less sensitive than those with + cloud feedback

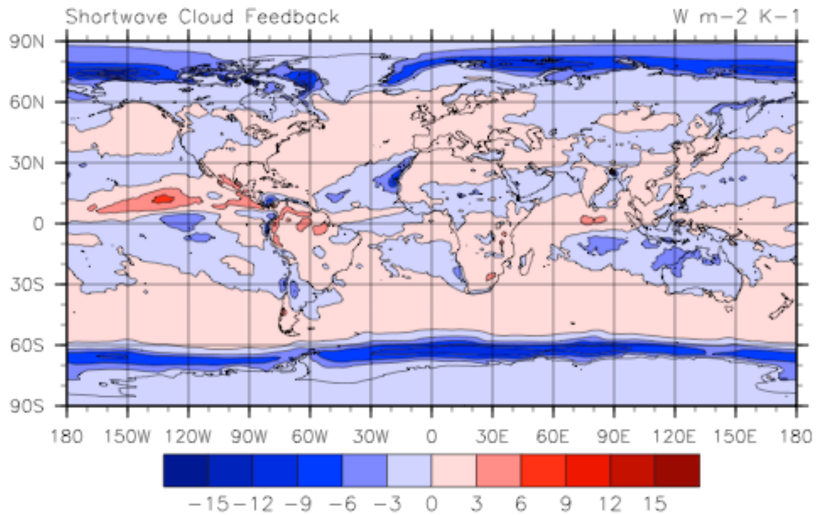
Low cloud area decreases result in less cooling (+ feedback) and higher sensitivity



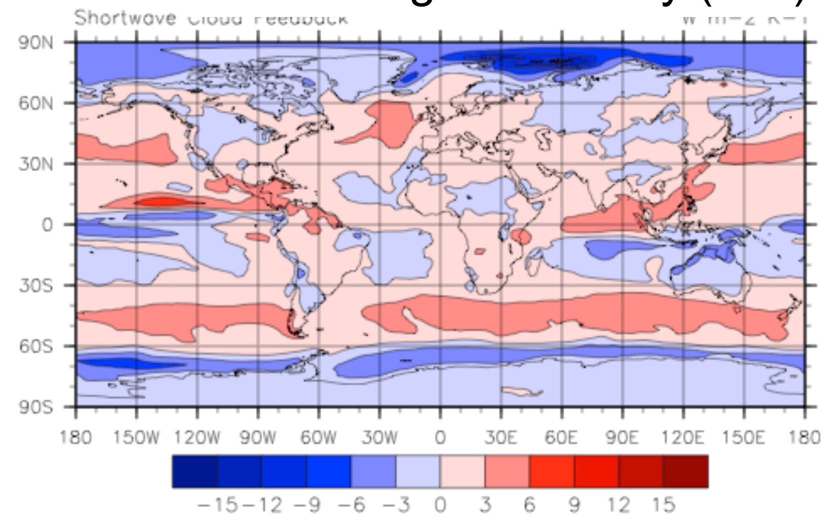
Stephens, 2005, J. Climate

Shortwave (Solar) Cloud Feedbacks

CAM4: Low sensitivity (3°C)



CAM5: High sensitivity (4°C)



Clouds are the major difference in climate sensitivity in these models !

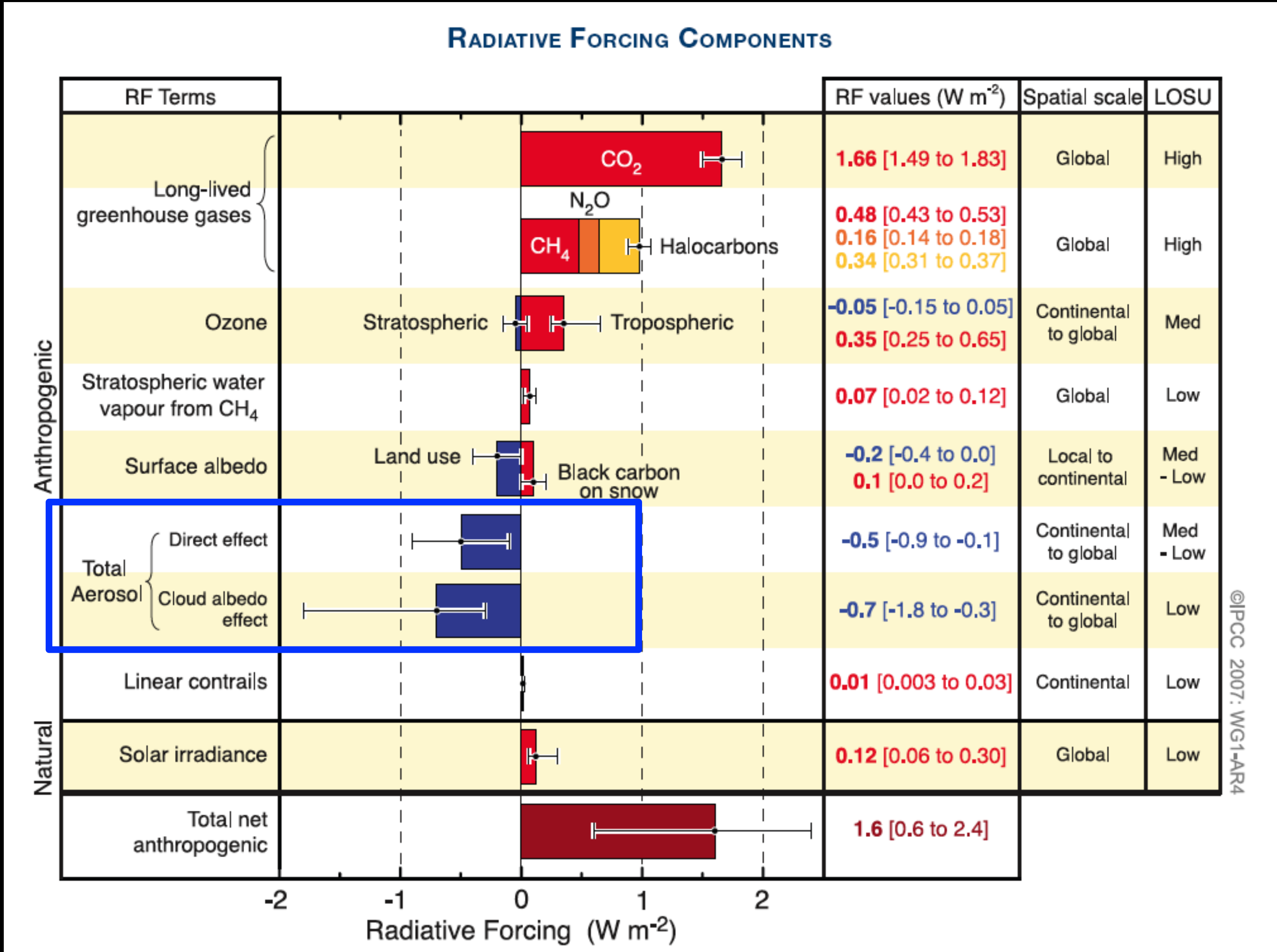
Trace feedbacks to regions:
- Equatorward flanks of storm tracks over the oceans
- Significant impacts of cloud processes in the Arctic

Trace feedbacks to processes:
The response of shallow convective clouds to warming

Summary: Feedbacks

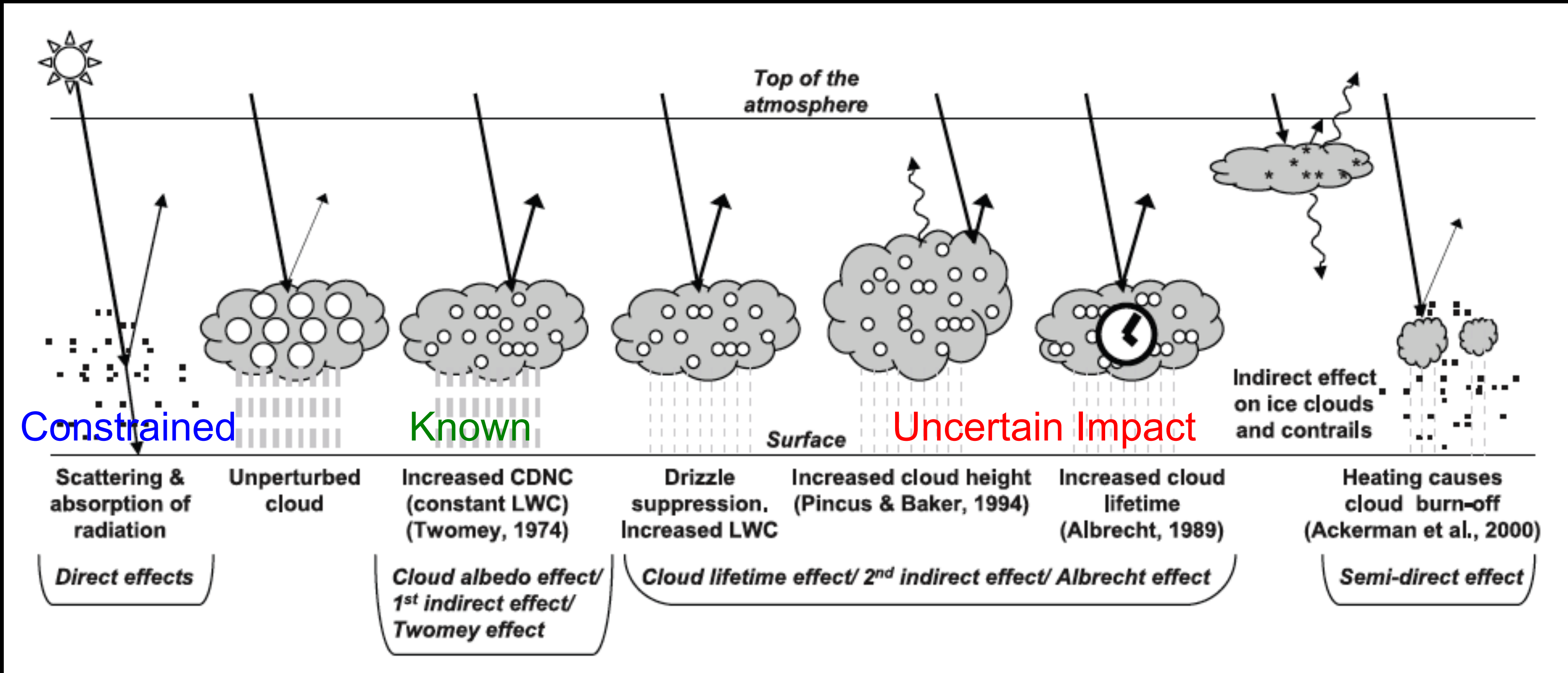
- Cloud Feedbacks are the biggest uncertainty
- Need to evaluate responses of cloud regimes
  - Need statistics to represent processes.
  - Fast physics: don't need 50 years for progress
  - Global observations to help parameterize clouds
- Resolutions: models going to 5-25km
  - Still need parameterizations
  - Need vertical information on cloud microphysics, especially radiatively important quantities (particle sizes) and liquid/ice contents, precip
  - Multi-parameter view critical: interactions with environment

Radiative Forcing: Aerosols



IPCC 2007 Policymakers Summary Figure 2

Aerosol-Cloud Interactions



- Direct effects: Cool
- Indirect Effects: Cool
- Indirect effects on precipitation

Radiative Forcing

Precipitation impact

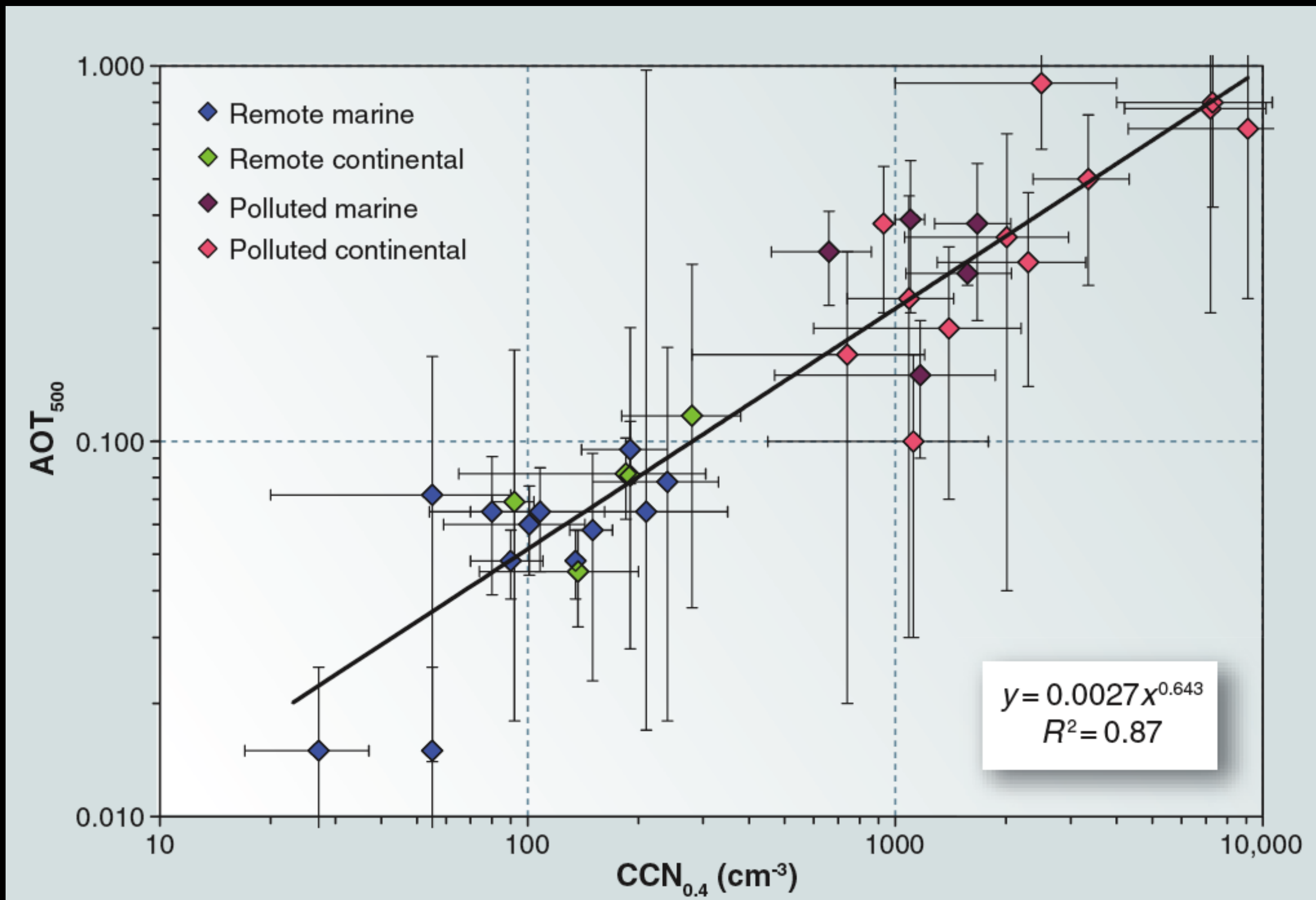
Aerosol-Cloud Interactions (2)

Direct effects: aerosols scatter & absorb radiation

Aerosol Indirect Effects (AIE):

- Aerosols act as Cloud Condensation Nuclei (CCN)
  - Sea Salt, Sulfate, Dust
- Aerosols may also be Ice Nuclei (IN)
  - Dust, Sulfate, Soot?
- More CCN →
  - More, smaller drops & brighter clouds (Albedo Effect)
  - Smaller drops may settle slower with longer lifetime & less precipitation (Lifetime Effect)
- Models typically show larger impacts than observed

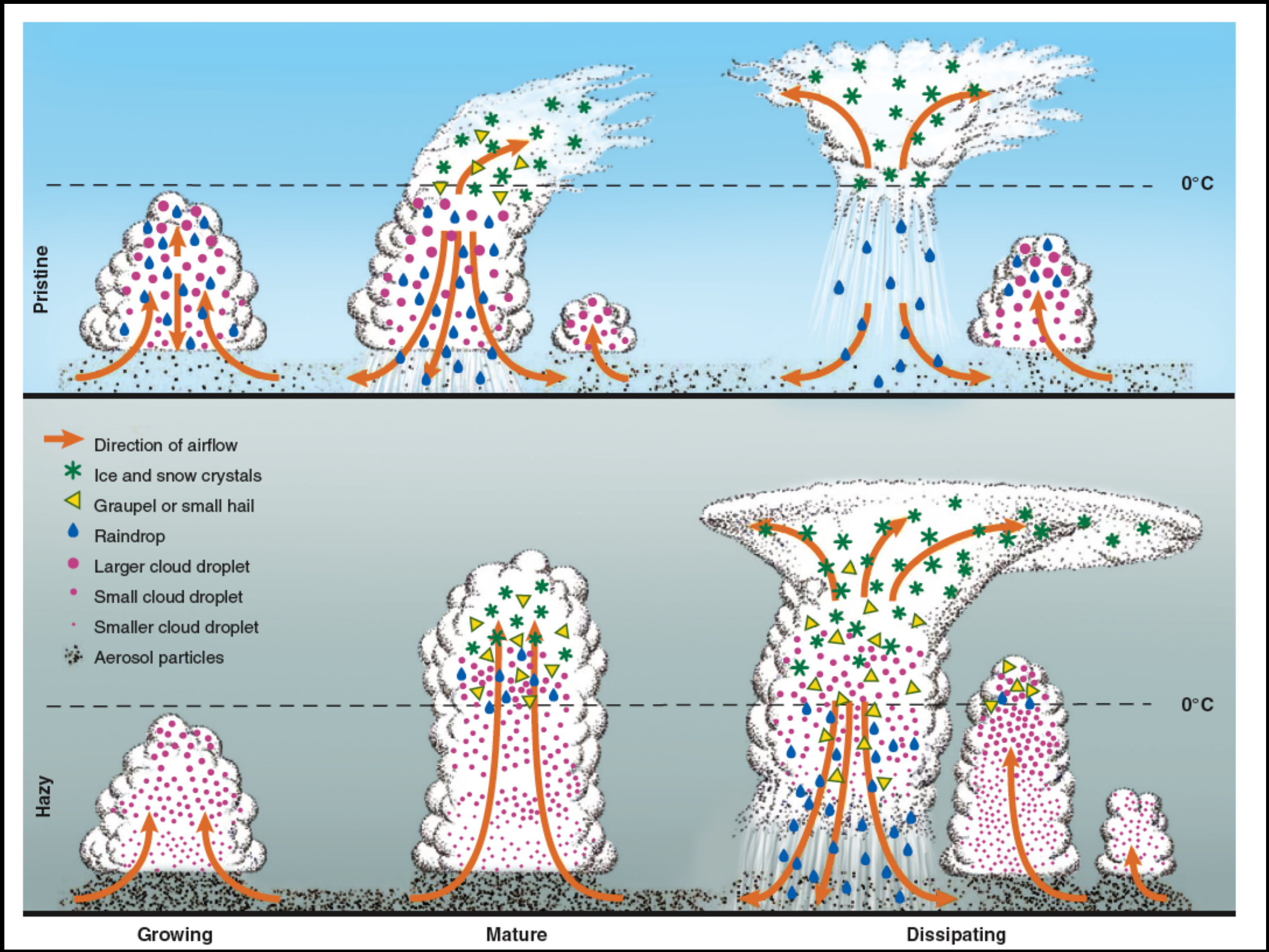
Cloud Nuclei v. Aerosol Absorption



Albedo Effect: Rosenfeld et al, Science 2008

Why AIE Matter: Precipitation

Rosenfeld et al, Science 2008



Aerosols delay precipitation:

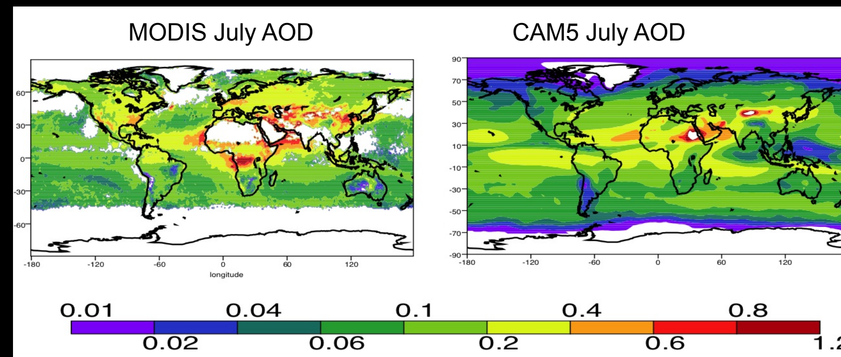
but may make it more intense (also depends on ice)

Evaluation of AIE

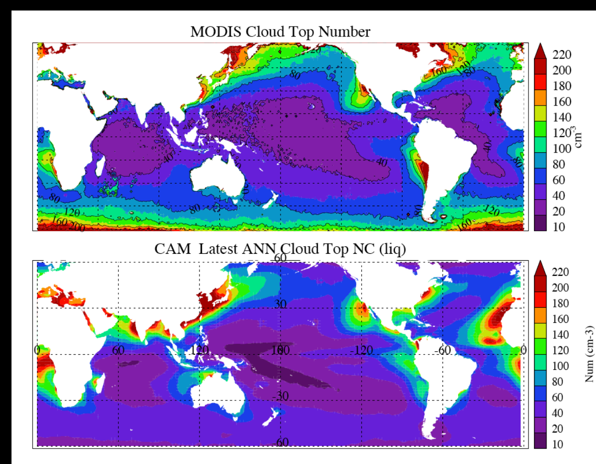
- 'Local' Evaluation (v. field observations)
- Regional/Global Evaluation (v. Satellites)
- Difficulties:
  - Correlation is not causation
  - Co-variance with meteorological state
  - System may be heavily 'buffered' with competing effects (e.g.: precipitation effects)

Current observations provide 'Necessary but not Sufficient' Tests

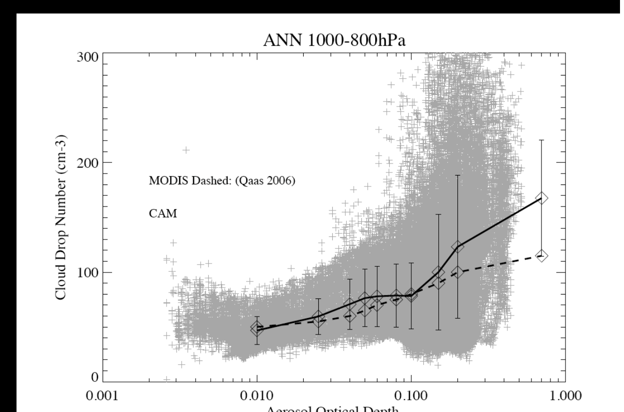
- Aerosol: (e.g. AOD)



- Microphysics:
  (Drop Number)

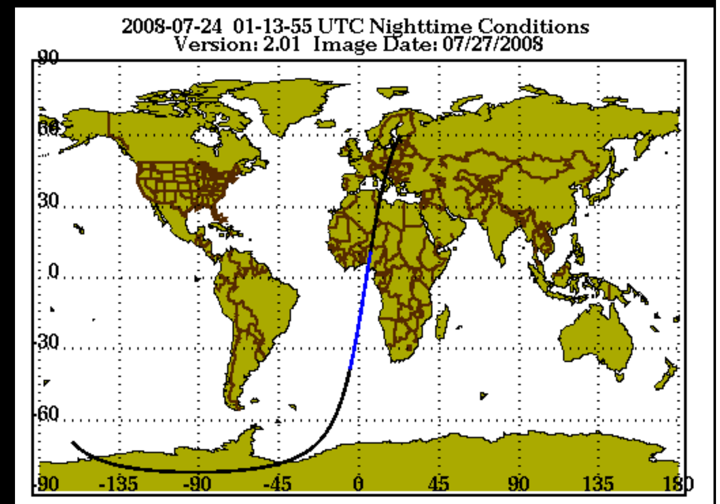


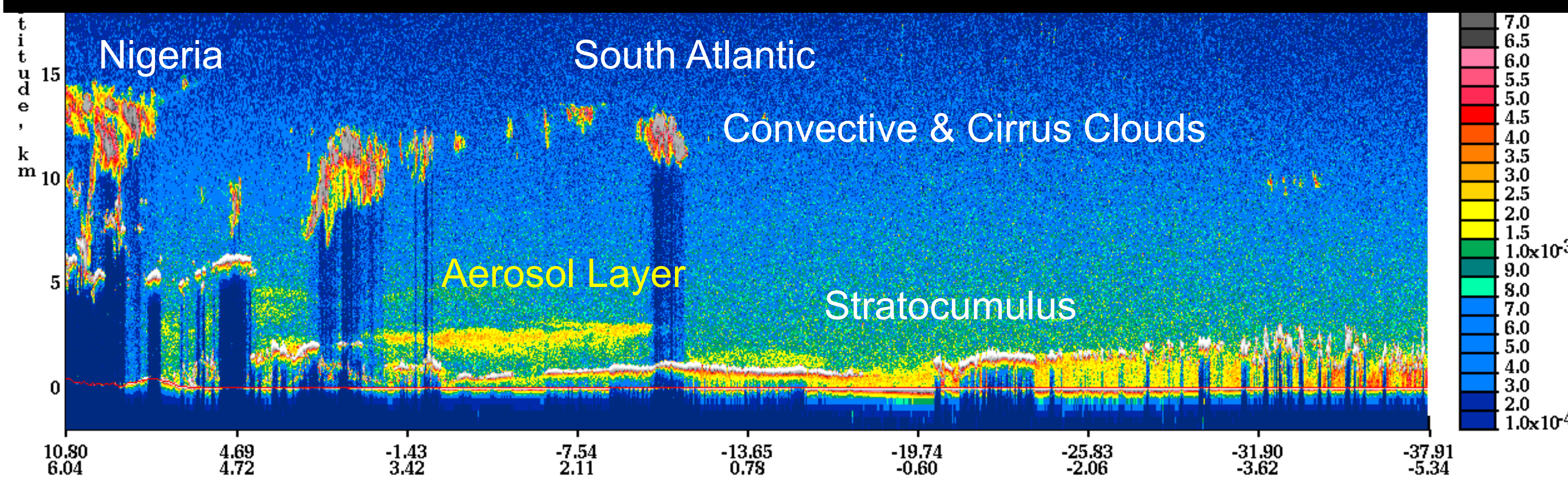
- Co-Variability:
  (AOD v. Drop Num)

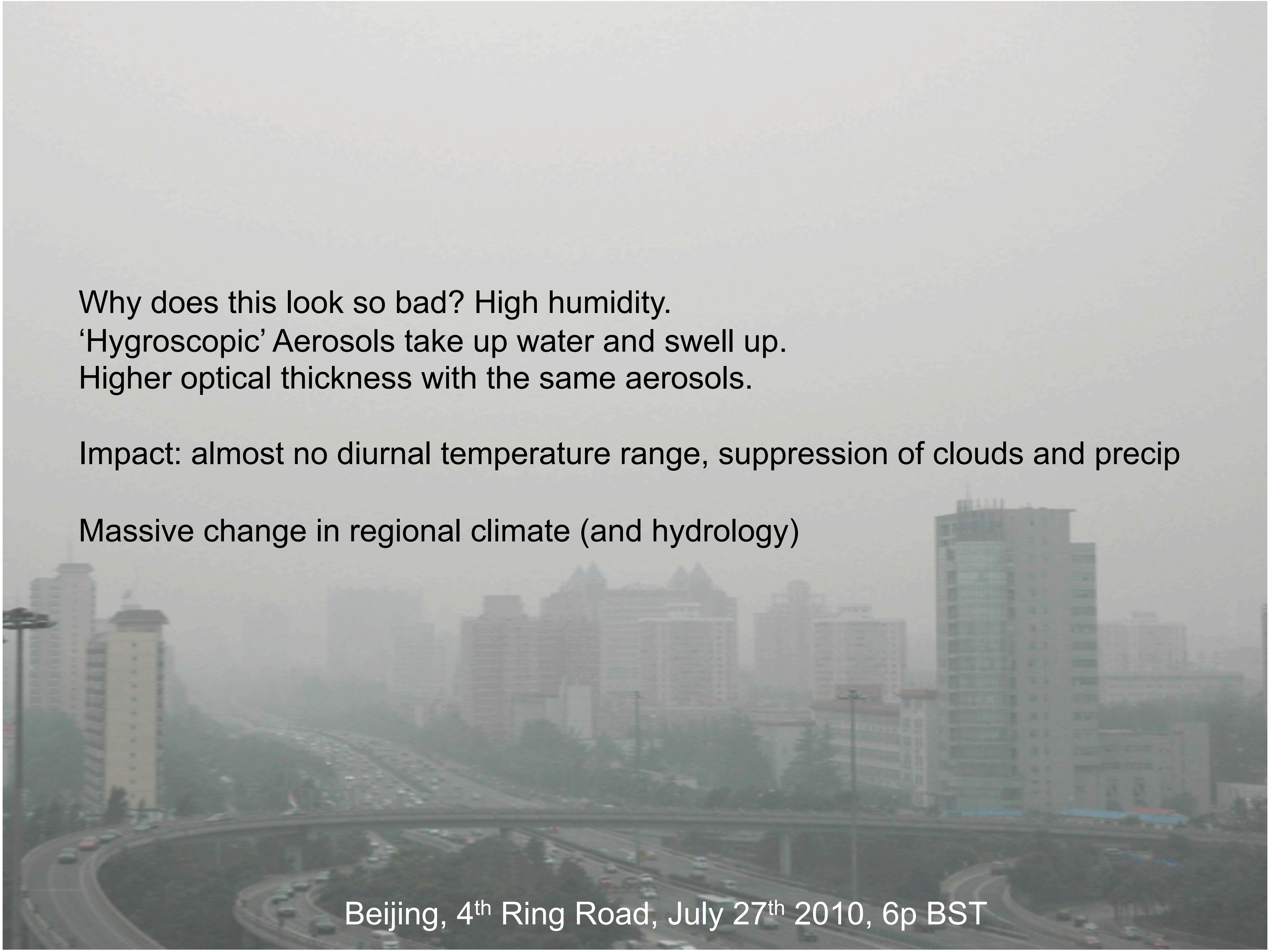


But: Correlation is not Causation

1. Vertical Structure: CALIPSO Lidar, July 2008:
   W. African Coast & S. Atlantic:
   Aerosol rides OVER Stratocumulus
2. Correlations to a 3rd variable:
   E.g.: AOD & Clouds correlated, but both correlated with humidity and wind speed






Why does this look so bad? High humidity.
'Hygroscopic' Aerosols take up water and swell up.
Higher optical thickness with the same aerosols.
Impact: almost no diurnal temperature range, suppression of clouds and precip
Massive change in regional climate (and hydrology)
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Where observations are now

A-Train Synergy:

- MODIS (column maps), CloudSat (cloud vertical structure), CALIPSO (aerosol vertical structure), AIRS/MLS (humidity)
- TRMM (precip)
- Problems
  - Limited vertical information on aerosols, clouds
  - Precip (TRMM) not linked to cloud microphysics

Aerosol Summary

- Aerosols are biggest uncertainty in narrowing current forcing: helps with understanding climate sensitivity!
- Aerosols may perturb the hydrologic cycle and alter precipitation patterns and intensity.
- We cannot observe these processes sufficiently to constrain models
- Cloud and aerosol microphysical processes, and process interactions are the largest uncertainty

Overall summary

- Model uncertainties in climate predication are related to cloud physics (cloud feedbacks) and aerosol cloud interactions (climate forcing)
- Model processes (especially aerosol-cloud interactions) are pushing observational limits: they cannot constrain effect further
- Need multi-sensor platforms for simultaneous vertically resolved observations of clouds, aerosols and precipitation to make progress